Chapter-5

The gist of climate change

PAST CLIMATES

Climate has varied in the past on many time scales. There have been long periods (~ 50 million years) of relatively undisturbed climates, generally warmer than the current climate, interrupted by shorter periods (a few million years) of quite variable climates. For the past 2 million years, we have been in such a disturbed period, with ice ages alternating with somewhat mild interglacial periods. The last ice age ended about 10,000 years ago; since then there have been minor climate fluctuations like, a warm period at about 1000 AD and a “little ice age” in the second half of the 17th century. In the 20th century, the atmosphere warmed by about 0.5^{0}C from 1880 to 1940 and cooled from 1940 to at least 1970.

Many reasons for historical climate changes have been suggested: changes in the earth’s crust (e.g., migration of the continents, mountain buildings, and volcanic eruptions); changes in atmospheric composition, particularly the amount of carbon dioxide; changes in earth–sun geometry; and changes in solar heat output.

Of course, it is quite possible that some of these factors worked together, but most important climatic variations on different time scales do not have the same causes. At least, past climates have not been affected by human activity; the same cannot be said about future climates.

Climate changes on the longest time scales considered here (~ 50 million years) almost certainly were affected by changes in the earth’s crust; for example, it is possible that the active periods coincided with periods of mountain building; and perhaps, ice ages occurred when there were landmasses near the poles.

The causes of climate change *within* the disturbed periods, which have time scales of 10,000 to 100,000 years, are now fairly well understood. We have good records from undersea and under ice cores and we have a good quantitative theory that agrees with these records. This theory was proposed in 1926 by Milankovich but has been taken seriously only since about 1970. It is known from quantitative celestial mechanics (and from observations) that several characteristics of the earth–sun geometry are variable. For example, the earth’s axis does not point in the same direction in space at all times, but precession with a period of 26,000 years. At the same time, the major axis of the earth’s orbit spins in the opposite direction. The net result is that, about every 20,000 years, the sun and earth are closest in northern winter (as they are now). So right now, northern winters are relatively mild and southern winters are relatively cold. After ten thousand years from now, this situation will be reversed. A second factor is the eccentricity of the earth’s orbit. Right now, the difference between aphelion and perihelion distance is about 3%, but the distance difference has been as large as 10% and at other times the orbit has been circular. The period of this variation is 100,000 years. Finally, the angle between the earth’s Equator and the earth’s orbit has varied from about 22 ^{0} to 24.5 ^{0}, with a period of 40,000 years. When this angle is largest, seasonal contrasts are largest.

None of these factors affect significantly the total radiation received by the earth, but they all affect seasonal contrast. Milankovich suggested that ice ages result when there are cool summers and mild winters, since snowfall can be heavy in mild winters, and less snow melts in cool summers.

The chronology of observed ice ages in the past million years agrees well with predictions of the Milankovich theory; in particular, the various periodicities have been found in the geological records. Climate models have some difficulties with the phases of the largest cycles, but there are satisfactory theories to explain these difficulties. As a result, the basic theory is generally accepted as the explanation for climate changes on the scale of 10,000 to several hundred thousand years.

There is no generally accepted hypothesis to explain more recent climate changes. Solar activity has periods of 11, 21, and 80 years, but statistical analyses of relationships between solar activity and atmospheric variations have not been convincing, even though a period of low sunspot activity coincided with the little ice age, and
U.S. western and African droughts are correlated somewhat with the sunspot cycles. However, there are not much known mechanisms connecting solar activity with changes of climate.

There is some indication of cooling at the surface following major volcanic eruptions, but the effects are not large and it is not clear whether volcanoes produce long lasting changes. In short, there is no agreement concerning the causes of recent climate changes.

FUTURE CLIMATE CHANGES

As the Milankovich theory has been well established from past records, it should also provide some indication of future climate change, in the absence of complications produced by human activity. According to this theory, a cooling trend has already set in, will intensify in several thousand years from now, and will produce peak glaciations in about 20,000 years.
Superimposed on this scenario are natural short-period fluctuations, which we cannot predict because we do not understand their causes, and man-made changes. The most important of these are produced by increased CO_2 in the atmosphere, which is due to burning of fossil fuels and clearing of forests. Increases in atmospheric CO_2 have been measured and amount to about half of theCO_2 known to be emitted into the atmosphere; the rest is presumably absorbed by the ocean. After the year 2050, the amount of CO_2 in the atmosphere is expected to be double than that of the before the onset of the industrial age.

Increasing atmospheric CO_2 concentration enhances the natural “greenhouse effect,” thus causing surface warming. As soon as warming begins, increasing evaporation increases the amount of water vapor in the atmosphere, producing even more warming. Many climate models have been run with increased CO_2 concentrations, typically double the normal. A consensus is starting to emerge among modelers that doubling CO_2 concentration results in a global average warming of 2^0 to 3^0 C and polar warming of more than twice that amount. Warming due to increased CO_2 is not yet large enough to be observed in view of irregular temperature variations. It is expected that CO_2 warming will be detected in the future, if the models are correct.

However, most of the models accounting for increased CO_2 are unrealistic in the specification of clouds and possibly in the lower boundary conditions. For example, it is not known whether warming will increase cloudiness or change the physical characteristics of clouds. In particular, clouds may thicken and reflect more sunlight, limiting the warming effect.

Other long-term atmospheric impacts resulting from human activity are also being monitored. Of late is the role of chlorofluorocarbons (CFCs), multiuse chemicals best known as refrigerants. Chemical

breakdown of CFCs in the ozone layer of the stratosphere results in a chemical reaction leading to the diminution of ozone. The decrease modifies the role of ozone in screening solar radiation, resulting in an increase in shortwave ultraviolet radiation reaching the earth's surface.

Few environmental problems have been received the attention of the media regarding the problem of global warming. The continued rise of atmospheric CO_2 content, the warmth of the 1980s and particularly the 1990s, and the three warmest years on record (1998, 1997, 1995), suggest that the global warming suggested by computer models is correct and the warming is already on the way at present. Forecasts of increasing warmth, melting ice caps, rising sea levels, and modified environments have been widely reported. Given such forecasts, attempts have been made to introduce legislature to limit the burning of fossil fuels and, hence, CO_2 production. Notably, the Earth Summit in Rio de Janerio, Brazil, marked an important global moment of recognition of the significance of potential human impacts on climate. Further, the Climate Conference in Kyoto, Japan, in 1998 provided a substantive basis for the reduction of greenhouse emissions and a procedure for monitoring the success of mitigation efforts. The latter document lists the Intergovernmental Panel on Climate Change (IPCC) as the authority for all scientific decisions. No definitive action has yet been taken.

The relative lack of political action, particularly by the developed nations, reflects the economic costs involved and the varying interpretations of the global warming signal. Models do not provide a uniform interpretation of the future. While most climatologists agree that the earth will experience a warming trend, there is disagreement on how much the temperature will rise and when the impacts will be felt by the human population. While most models predict modest warming, an alternative scenario suggests that high latitude warming could initiate a cooling episode. The mechanism for this scenario is fairly complex, involving adjustments in the North Atlantic Deep Water oceanic circulation, and overall implications are unclear. As global models become more refined, the answers to the problem will become clearer.
In contrast to the paucity of action concerning the CO_2 problem, appreciable headway has been made in combating the ozone depletion problem. Most industrial nations that produce CFCs have agreed to curb the production and examine for the substitute chemicals. Such action will take time and the depletion of ozone continues to be of concern. Atmospheric scientists are now examining the dynamics that cause "ozone holes" that periodically occur in the polar ozone layers.

Given the current interpretation of climate, speculations concerning future climates are possible. If the GCMs are correct and no preventive measures are taken, substantial global warming will take place over the next few hundred years. Eventually, perhaps after 1000 years, most fossil fuels will have been used and excess CO_2 will be taken up by the oceans. The Milankovitch mechanisms will then take over to lead, potentially, to a global cooling. Thus Climate change has occurred in the past and will occur in the future also even without anthropogenic causes.